(a) A crystal of strontium iodide doped with europium for gamma-ray detection is an R&D 100 Award winner. (b) The crystal is encapsulated when used in a radiation detection device and (c) glows blue when exposed to ultraviolet light.

A Scintillating Radiation Detection Material

ENSURING that the country remains safe from a nuclear or radiological attack is driving the search for more definitive radiation detection and identification technologies. The Department of Energy has for decades been building the science and engineering basis for detecting illicit sources of plutonium and uranium. Then, in 2005, the Department of Homeland Security (DHS) made a bold request to develop significantly more effective materials to detect gamma rays. The search began in earnest for new materials for smaller, faster, and more accurate sensors that would improve the nation's ability to unambiguously identify radiation from illicit sources.

Lawrence Livermore and Oak Ridge national laboratories, Fisk University, and Radiation Monitoring Devices, Inc., in Watertown, Massachusetts, joined forces with DHS to develop and optimize new detector materials. Livermore's Steve Payne and Nerine Cherepy are leading the collaboration. "After a lengthy process of scouring the literature and synthesizing and evaluating potential materials, we determined strontium iodide doped with europium to be a winner," says Cherepy. The team has received an R&D 100 Award for their work.

Livermore development team for the strontium iodide scintillator: (from left) Steve Payne, Nerine Cherepy, Owen Drury, Alex Drobshoff, Cheng Saw, Ben Sturm, Thomas Hurst, Scott Fisher, and Peter Thelin.

Improving on the Competition

Detectors made of high-purity germanium, a semiconductor, have long offered the best energy resolution, allowing precise identification of the gamma rays emitted by plutonium and uranium. However, detectors based on germanium require special cooling, making them costly and heavy to use. For field use, radiation detectors must be inexpensive and robust, operate at ambient temperature, provide high detection efficiency, and be small enough for covert operations.

An effective detector must also provide unambiguous identification of a material. Such discrimination is needed because only some gamma-ray energies are indicative of a radiation source that poses a threat. A detector must also pick up very weak signals, such as those from plutonium heavily shielded with lead. Current detector technology is limited in its ability to meet these requirements.

An alternative to semiconductors is scintillators, in which radiation interacts with a material to produce a brief but measurable flash of light. The Livermore-led team hunted for a material that would produce the brightest flash of light when exposed to plutonium or highly enriched uranium. The precision of the scintillator material's response, or energy resolution, defines the material's ability to distinguish between gamma rays that have similar energies.

The most prominent scintillator material in use today is thallium-activated sodium iodide, NaI(Tl), because it is easy to grow in large sizes and is therefore inexpensive. However, its energy resolution is poor compared to semiconductors. Lanthanum bromide doped with cerium offers the highest energy resolution among commercial scintillators, but it is difficult and costly to grow and is inherently radioactive because of the presence of lanthanum-138.

Start from Square One

"DHS recognized the potentially transformational impact that better detector materials could have on our radiation detection capabilities," says Payne. "So the collaboration essentially started by taking out a clean sheet of paper and asking, 'What is possible?'"

They crossed off elements on the periodic table that were not usable because of such properties as optical absorption, radioactivity, or having too low an atomic number to exhibit reasonable gamma absorption efficiency. From the literature, the team assembled a list of prospective materials. They then synthesized small samples of the candidates and evaluated the scintillation properties, eliminating many. Finally, the team created a short list of about two dozen candidates and thoroughly investigated the properties, ultimately identifying strontium iodide doped with europium, SrI_2(Eu), as the material having overall the most useful set of properties.

SrI_2(Eu) can be easily grown, resists cracking, and has no radioactive constituents. The material also exhibits a phenomenon known as better light-yield proportionality. "It turns out," says Payne, "that the fundamental limit to scintillator resolution is dictated by nonproportionality." Proportionality is a direct measure of how much the light yield (divided by electron energy) varies as a function of the electron energy. If a scintillator were perfectly proportional, the relative light yield would be a horizontal line at 1 for all electron energies. No material is perfectly proportional; however, the closer the relationship is to a horizontal line, the better its performance. Compared to existing commercial materials, SrI_2(Eu) hews most closely to this horizontal line.

Putting the Winner to Use

The packaged SrI_2(Eu) scintillator can be easily incorporated into the handheld radiation detectors being produced by many companies and would enhance performance considerably. The Laboratory's Industrial Partnerships Office is in negotiations with several detector suppliers as a replacement for NaI(Tl).

The SrI_2(Eu) scintillator can potentially serve a wide range of applications that use gamma-ray spectroscopy to identify radioisotopes. Isotope identifiers are a common tool for professionals in medicine, police and fire services, and mining operations.

Last year, DHS ordered 20 scintillators, similar to the crystal shown on p. 4, for use in experimental homeland security detection devices. Says Cherepy, "With its poorer energy resolution, thallium-activated sodium iodide cannot pick out the specific gamma rays of plutonium and uranium nearly as well as our award-winning material. Strontium iodide doped with europium offers the best scintillator option yet for detection of potentially devastating radiological materials."

—Katie Walter

Key Words: gamma-ray spectroscopy, R&D 100 Award, radiation detection, radiological attack, strontium iodide scintillator.

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